COMPARISON OF REGIONAL AND GLOBAL LAND COVER PRODUCTS AND THE IMPLICATIONS FOR BIOGENIC EMISSIONS MODELING

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1. INTRODUCTION

Isoprene and monoterpenes are among the most significant biogenic volatile organic compounds (BVOCs) emitted from vegetation, due to their relative abundance (Sindelarova et al., 2014), high chemical reactivity (Chameides et al., 1988), and contributions to the formation of ozone and secondary organic aerosols (Atkinson, 2000; Claeys et al., 2004). For most biogenic emission models, land cover characterization, as an essential driving variable, determines the phenological emission potential of a region. Previous studies have reported the influences of different land cover representations on modeled biogenic emissions and subsequent ozone predictions at regional and global scales (e.g. Byun et al., 2005; Guenther et al., 2006; Steinbrecher et al., 2009).Texas has highly diverse land use/land cover profiles over its ten climate regions; the major land cover types change from grasses and crops in the central regions to heavily forested areas towards the east. Annual biogenic emissions in Texas ranked first within the continental United States in the 2011 National Emission Inventory. The objective of this work was to investigate the influences of land cover characterization on the estimation of isoprene and monoterpene emissions by the Model of Emissions of Gases and Aerosols from Nature (MEGAN) over eastern Texas using the Moderate Resolution Imaging Spectroradiometer (MODIS) global land cover product (MCD12Q1) and a regional product with high spatial resolution and detailed land cover categories developed by Popescu et al. (2011) for the Texas Commission on Environmental Quality (TCEQ). MEGAN simulations were conducted to examine the influences of different land cover datasets on the standard emission potential and emission activity factors, both separately and simultaneously.

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2. METHODS

2.1 MODIS Land Cover Product (MCD12Q1)

The latest version of MODIS land cover product – version 051 (MCD12Q1; Friedl et al., 2010) provides five types of land cover schemes at annual time steps and 500-m spatial resolution. Type 3 of the MODIS land cover employs the biome scheme described by Myneni et al. (1997) and was used in this work as a contrast to the TCEQ land cover data. To facilitate direct comparisons between the MODIS and TCEQ land cover products, a mapping crosswalk was developed (using year 2011) to convert the MODIS and TCEQ land cover classifications to a simplified set of seven categories: water, urban, non-vegetated, grasses and crops, forest, shrubs and savanna. The MODIS land cover also provides the plant functional type scheme (Type 5) described by Bonan et al. (2002), which was mapped to MEGAN's default 16 PFT scheme.

2.2 TCEQ Land Cover Product

The TCEQ has sponsored the development of a regional land cover product for eastern Texas by combining three existing databases: LANDFIRE (previously known as the Landscape Fire and Resources Management Planning Tools Project from 2004 to 2009), the 2001 National Land Cover Dataset (NCLD), and the Texas Parks and Wildlife Department (TPWD) Texas Ecological System Classification Project (Popescu et al., 2011). This regional land cover product consists of 36 land cover categories with high spatial resolution (~30-m) and has been utilized in previous work (Huang et al., 2014). The TCEQ land cover classes were mapped to MEGAN's default 16 PFTs. For each 1-km MEGAN grid cell, the fractional coverage of each of MEGAN's default PFTs was determined by summing the number of 30 m resolution cells whose centroid fell within a given grid cell.

2.3 MEGAN Configuration

The emission rate (F) of isoprene and monoterpenes in units of flux (µg m^{-2} ground area h^{-1}) is calculated as:

$$F = \gamma \cdot \sum \varepsilon_j \chi_j \qquad (1)$$

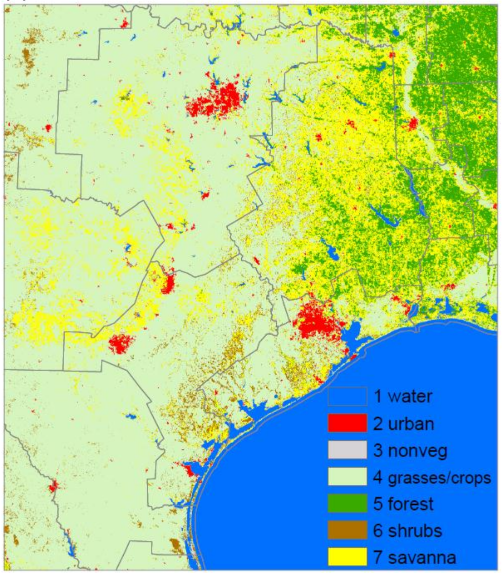
where ε is the basal emission factor for vegetation type j with fractional coverage χ_j within a model grid; for simplicity, we define the standard emission potential (SEP) in replacement of the summation term to represent the gridded emission rate under standard environmental conditions defined in Guenther et al. (2006, 2012); γ is the overall emission activity factor that accounts for variations in environmental conditions. The SEP can be directly determined by the PFT distribution and the PFT-specific emission factors or can be specified from prescribed gridded emission factor maps. The PFT distribution is also implicitly incorporated within the canopy environment model that is used to calculate the overall activity factor. The MEGAN configuration follows the approach of Huang et al. (2014). Three sets of MEGAN simulations were conducted over eastern Texas for March-October within a six-year period (2006-2011). The first set of MEGAN simulations (S1) characterized the influence of different land cover data on the SEP by artificially assigning the activity factor to be unity. For the second set of simulations (S2), only the emission activity factors were compared to demonstrate the differences caused by different land cover data. The influences on the SEP and emission activity factor were simultaneously examined in the last set of simulations (S3). For each set of simulations, parallel MEGAN runs were conducted using either the MODIS or the TCEQ land cover product while maintaining other inputs identical. Monthly isoprene and monoterpene emissions (or emission activity factors for S2) were compared for four climate regions in eastern Texas – North Central Texas, South Central Texas, East Texas and Upper Coast – which include most large metropolitan areas in the state.

3. RESULTS

3.1 Comparison between the MODIS and TCEQ Land Cover Products

Fig. 1 illustrates several large discrepancies exist between the two land cover products. As indicated by the MODIS dataset (Fig.1a), North and South Central Texas are dominated by grasses/crops with area percentages of 86% and 75%, respectively; forest coverage was negligible. In contrast, TCEQ land cover suggests significantly higher forest coverage (~23%) in central Texas with grasses/crops coverage of approximately 45% of the area. Less forest coverage in the MODIS data is also evident in East Texas and Upper Coast with underestimation by factors of 3.6 and 4.8, respectively, relative to the TCEQ data. Both land cover products suggest similar fractions of grasses/crops in East Texas (~27%) and the Upper Coast (~45%); however, savanna has much higher coverage in the MODIS data, especially in East Texas (~50%) while the TCEQ data indicates negligible coverage. Potential causes for these disagreements include differences in the classification methodology, the types of satellite sensors used, uncertainty associated with the reprojection, and differences in the data spatial resolution (McCallum et al., 2006; Pouliot et al., 2014; Quaife et al., 2008). The MODIS land cover product was developed using a top-down supervised approach based on 1860 training sites globally with an overall accuracy about 75% (Friedl et al., 2002, 2010); yet eastern Texas has not been well represented in the training sites. In contrast, the TCEQ land cover was specifically generated for air quality modeling in Texas and was developed by aggregating the much more detailed LANDFIRE classes into the Texas Land Classification System (Popescu et al., 2011). The accuracy of the LANDFIRE product in Texas and neighboring states to the northeast ranges between 60-84% and is expected to be higher when aggregated (Popescu et al., 2011). Reprojection of the MODIS dataset from the original sinusoidal projection to Lambert Conformal conic projection could result in some loss of data as suggested by Pouliot et al. (2014). The coarser spatial resolution of the MODIS land cover product (500-m) could also result in a loss of information regarding classifications when mixed surface types exist within a single pixel (Quaife et al., 2008). Nevertheless, the discrepancies between the two land cover datasets suggest that differences in land cover characterization have the potential to influence model predictions of isoprene and monoterpene emissions through PFT-dependent basal emission factor and emission activity factors.

(a)



(b)

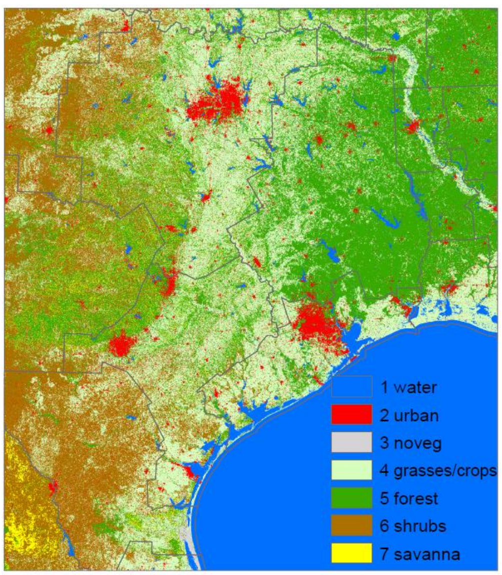


Fig. 1 Comparisons between the (a) MODIS land cover (year 2011) and (b) TCEQ land cover based on a simplified set of seven land cover categories: water, urban, non-vegetated, grasses/crops, forest, shrubs and savanna.

3.2 Sensitivity of Isoprene and Monoterpene Emissions to Land Cover Characterization

Standard emission potential (SEP)

With the emission activity factor assigned to unity, the resulting isoprene or monoterpene emission rate from Eq. 1 represents the standard emission potential (SEP). Fig. 2 shows the area-averaged isoprene and monoterpene SEPs for the four climate regions. For both land cover products, East Texas had the highest isoprene and monoterpene SEPs, attributed to the dense forest coverage among the four climate regions. In North and South Central Texas, the MODIS land cover characterization resulted in significantly lower values of isoprene (by 75-90%) and monoterpene (by 70-90%) SEPs relative to the TCEQ land cover. The substantially lower SEPs for MODIS were associated with the underestimation of forest coverage, because the basal emission factor of isoprene and monoterpenes assigned for forest are several magnitudes higher than those for grasses and crops (Guenther et al., 2012). In East Texas, isoprene and monoterpene SEPs were underestimated by 15% and 30%, respectively, using MODIS compared to TCEQ land cover. The relatively better agreement between the area-averaged SEPs in East Texas than in central Texas was attributed to the much higher coverage of savanna in the MODIS data. Similarly in Upper Coast, isoprene and monoterpene SEPs generated with the MODIS data were approximately 40% and 30%, respectively, less than with the TCEQ data. Among the four climate regions, East Texas exhibited the greatest interannual variations in SEPs generated from the MODIS land cover (as indicated by Fig. 2), which may be associated with the interannual fluctuations in the coverage of broadleaf trees (ranging from 15% to 34%) and shrubs (ranging from 4% to 20%) as suggested by the MODIS land cover data from 2006 through 2011.

Emission activity factor (γ)

In the MEGAN canopy environment model, land cover characterization is associated with the calculation of light and temperature distribution within the canopy and subsequently the overall activity factor (γ). In addition, the PFT distribution determines the root fraction profile within the soil layer that is used to calculate the soil moisture activity factor (Guenther et al., 2012), although the influences are expected to be negligible and were not considered in this study. The second set of MEGAN simulations (S2) specifically compared the overall emission activity factors generated between the two land cover products. Results show that the differences in the emission activity factors were generally negligible, especially during the summer season when isoprene and monoterpene emissions are greatest. This is because most PFT-dependent canopy parameters that are associated with the canopy environment

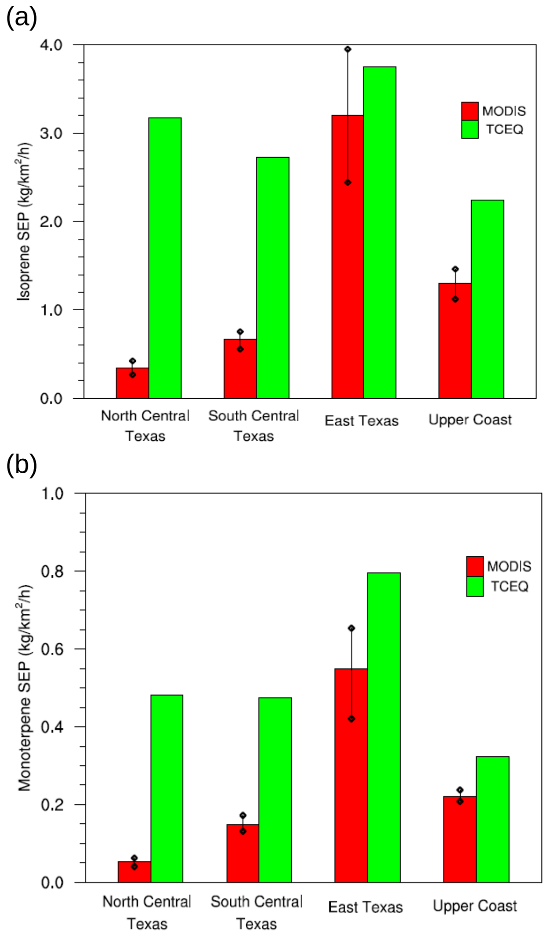


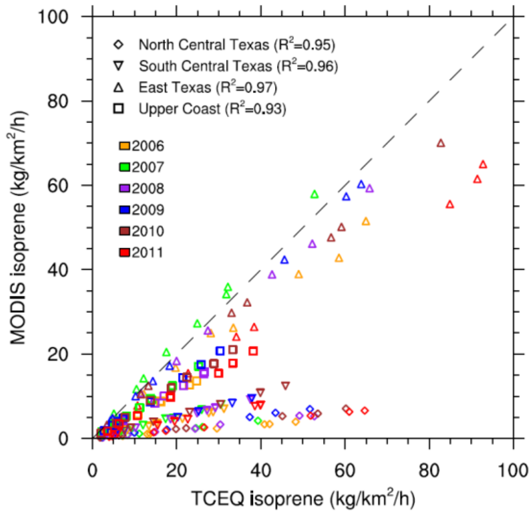
Fig. 2 Area-averaged (a) isoprene and (b) monoterpene SEP (in kg/km^2/h) generated using the MODIS (averaged over 2006-2011) and TCEQ land cover products. Black lines define the maximum and minimum range during 2006-2011.

model calculations such as leaf length and light scattering/reflecting coefficients, exhibit little or no difference among PFTs; only three parameters (canopy depth, canopy height, and leaf width) differ significantly between trees and low-growing PFTs. The canopy environment model is more sensitive to the external inputs, such as leaf area index (LAI) and temperature, which do not differentiate among PFTs. Moreover, averaging the emission activity factors over climate regions could also mitigate the impact caused by different PFT distributions. However, differences in the emission activity factor caused by assigning different PFTs could be large at a finer spatial scale. As a conceptual example, when a sample grid cell with meteorological fields for June 1st, 2011 and land cover assigned as 100% coverage of crop is changed to broadleaf evergreen tropical tree or broadleaf deciduous tropical tree, the total emission activity factor changes from 0.61 to 0.77, a 27% increase.

Estimation of isoprene and monoterpene emissions

For the third set of MEGAN simulations (S3), the impact of land cover characterization on isoprene and monoterpene emissions was considered by combining the differences in the SEP and emission activity factor. Fig. 3 contrasts the monthly area-averaged isoprene and monoterpene emissions generated by MODIS and TCEQ land cover for March-October during 2006-2011. Although the correlation coefficients between the two scenarios range from 0.93 to 0.98, substantial differences in the magnitudes of emissions estimates were apparent. MODIS-based estimates for both isoprene and monoterpenes were as much as 90% lower in North Central Texas than those generated with the TCEQ land cover characterization. Similar trends were evident in South Central Texas (isoprene and monoterpene predictions were ~75% and ~67%, respectively, lower with the MODIS land cover) and the Upper Coast (~40% and ~30%). Relative differences between monthly isoprene emissions in East Texas ranged from -35% (underestimated by MODIS in 2011) to 17% (overestimated by MODIS in 2007); for monoterpenes in East Texas, emissions predicted with the MODIS land cover were consistently lower than with the TCEQ land cover by 16% to 45%. The similarities between the results from S1 and S3 suggest that the influences of using different land cover data on isoprene and monoterpene emissions were primarily associated with the differences in the standard emission potential that are dependent on land cover characterization. It should be noted that even when the two land cover products predict similar area-averaged monthly emissions, substantial differences could exist spatially. When a prescribed emission factor map (provided by http://lar.wsu.edu/megan/) was utilized as a replacement of the PFT-dependent emission factors, the relative differences between monthly isoprene and monoterpene emissions generated from the two land cover datasets decreased substantially, again demonstrating that the major uncertainties in biogenic emissions associated with uncertainties in land cover data are from the PFT-dependent emission factors. Previous studies have also reported differences in biogenic emissions caused by different PFT distributions at global or regional scales (Kim et al., 2014; Pfister

(a)



(b)

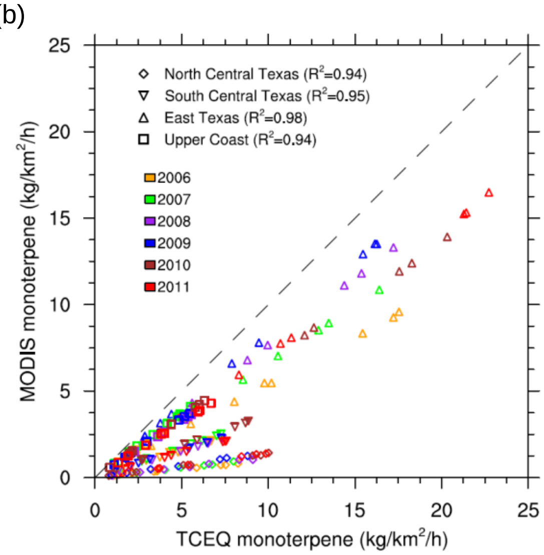


Fig.3 Scatter plots of monthly area-averaged (a) isoprene and (b) monoterpene emissions generated from MODIS and TCEQ land cover data for March to October during 2006-2011 (October 2008 was not shown due to missing data).

et al., 2008), but are smaller than those observed in this study. For example, Kim et al. (2014) reported differences in biogenic emissions over a 3km x 3km domain covering the Seoul, Gyeonggi, and Incheon Metropolitan Areas by 4.2 Gg (corresponding to a 15% relative difference) for May-June in 2008, resulted from three PFT scenarios. The much higher spatial resolution (1km x 1km) and temporal LAI resolution (4 day) employed in this study might result in the significantly different isoprene and monoterpene emissions (by as much as a factor of ten) between the two land cover products in the central regions of Texas.

4. CONCLUSIONS

This work contrasted two land cover products that are available for eastern Texas and investigated the influence of different land cover characterization on estimation of isoprene and monoterpene emissions by MEGAN. In general, forest coverage was significantly underestimated in the global MODIS land cover product compared to the regional TCEQ product, which resulted in differences in monthly isoprene and monoterpene emissions by as much as a factor of ten in central Texas. Influences of land cover characterization on isoprene and monoterpene emissions are dominated by contributions to the differences in the standard emission potential that are PFT-dependent; differences in the MEGAN overall activity factor associated with different land cover were generally negligible in this analysis. Improved validation of land cover products at regional scales or use of prescribed emission factor maps derived from in-situ measurements could potentially reduce uncertainties in modeled biogenic emissions.

5. ACKNOWLEGMENTS

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